

Analysis of South China Sea Shelf and Basin Acoustic Transmission Data

Ching-Sang Chiu

Department of Oceanography

Naval Postgraduate School

Monterey, CA 93943-5001

Phone: (831) 656-3239

Fax: (831) 656-7970 E-mail: chiu@nps.edu

Award #: N0001409WR20020

LONG-TERM GOALS

My long-term research goals are: (1) The characterization, understanding, and prediction of the statistics (mean, variance and coherence) of low-frequency acoustic signals and ambient noise in the littoral zone. The signal statistics are primarily influenced by the ocean variability and bottom properties. The noise statistics are influenced by atmospheric forcing and shipping in addition to the ocean and bottom variability. (2) The development and improvement of inverse techniques for measuring the dynamics and kinematics of meso and finer-scale sound speed structure and ocean currents in coastal regions. (3) The understanding of three-dimensional sound propagation physics including horizontal refraction and azimuthal coupling and the quantification of the importance of these complex physics in the prediction of sound signals transmitted over highly variable littoral regions.

OBJECTIVES

My current research focus is to complete the analysis of both the shelf and basin acoustic transmission data collected from the Northeastern South China Sea (NE SCS) during the Windy Island Soliton Experiment (WISE). These data were collected between April 2005 and October 2006.

The objectives of the NE SCS shelf acoustic data analysis are twofold: The first is to compare and contrast, in terms of phenomenology and statistics, the sound intensity fluctuations resulting from a transmitted acoustic pulse through nonlinear depression internal waves, nonlinear elevation internal waves and/or a mix of both types of waves. The second is to develop and validate a modified theory which expands upon previously established theories of the statistics of sound intensity fluctuations (Dyer, 1970, and Makris, 1996) by incorporating critical signal parameters and channel characteristics including signal and channel bandwidths, multipath arrival times (separations) and additional bottom-induced variance, all of which control the number of independent intensities/arrivals in the received signal.

The primary objective of the basin acoustic data analysis is to study and characterize the supertidal-to-seasonal-scale impacts of the transbasin nonlinear internal waves on long-range transmission loss. Additionally, a secondary objective is to understand the variability of the observed ambient noise level

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Analysis Of South China Sea Shelf And Basin Acoustic Transmission Data			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School,Department of Oceanography,Monterey,CA,93943			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT My long-term research goals are: (1) The characterization, understanding, and prediction of the statistics (mean, variance and coherence) of low-frequency acoustic signals and ambient noise in the littoral zone. The signal statistics are primarily influenced by the ocean variability and bottom properties. The noise statistics are influenced by atmospheric forcing and shipping in addition to the ocean and bottom variability. (2) The development and improvement of inverse techniques for measuring the dynamics and kinematics of meso and finer-scale sound speed structure and ocean currents in coastal regions. (3) The understanding of three-dimensional sound propagation physics including horizontal refraction and azimuthal coupling and the quantification of the importance of these complex physics in the prediction of sound signals transmitted over highly variable littoral regions.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

in the basin and quantify what portion, if any, of this variability is related to the nonlinear internal wave activities/climatology.

APPROACH

Shelf Transmission: The vertical line array (VLA) data is pulse-compressed, motion-compensated, and analyzed for sound intensity as a function of depth and time. Characterizations of the observed intensity fluctuations, in terms of both phenomenology and statistics, are made. In parallel, the oceanographic measurements obtained by the environmental moorings and the shipboard surveys are analyzed using empirical-decomposition and time-series methods to deduce the space-time structure of the sound-speed changes produced by the internal waves. A coupled normal-mode model (Chiu et al., 1996) is employed to examine the propagation physics by linking the observed sound-speed structure to the observed features and statistical properties of the intensity fluctuations.

Basin Transmission: A hypothesis under this investigation is that a major portion of this acoustic variability is induced by the evolution of the transbasin internal tides and waves that are modulated by mesoscale events and seasonal cycles. The detailed analysis of the basin transmission was commenced in FY08 and continued in FY09. The basin data is first processed for the pulse arrival structure as a function of transmission time. Motion compensation is applied in the processing. Using these pulse responses, time series of transmission loss and of travel times of arrivals are derived, and then their multi-scale variability analyzed with the aid of all oceanographic data measured along the transmission path over the same one-year period and acoustic propagation models.

WORK COMPLETED

In the shelf experiment, a moored 400-Hz sound source, a moored vertical line hydrophone array, moored temperature strings and a towed Scanfish CTD were employed to obtain simultaneous measurements of the fluctuating acoustic signal intensity and of the variable sound speeds for a period of three days in April 2005. Applying time-series filtering, principal component analysis and a feature tracking technique to the oceanographic data, a continuous space-time empirical model for the sound-speed field was developed. Using a coupled-mode sound propagation model, interfacing with the sound-speed model, the temporal variations of the vertical distribution of signal intensity at the hydrophone array were computed. Analyzing the model results and comparing them to the measured signal intensities have allowed for quantification and comparison of the effects of the nonlinear internal tides, depression waves, and elevation waves on the sound transmission.

The basin experiment began in April 2005 and ended in October 2006. It entailed seasonal cruises to maintain a moored source and a moored receiver monitoring the periodic transmissions of a 400-Hz signal across the basin. The observed temporal variability in the statistics of the acoustic travel time and intensity were analyzed using time-series techniques and preliminary modeling results with emphasis to elucidate the connection and sensitivity to the observed ocean variability.

RESULTS

During the basin experiment, oceanographic sensors observed large-amplitude internal waves propagating from the Luzon Strait region, through the deep basin, onto the northeastern shelf and the Dongsha Plateau of the South China Sea from Spring through Fall. In a parallel effort to measure the effects of these transbasin internal waves on long-range, low-frequency sound propagation, an acoustic

source with a center frequency of 400-Hz and a bandwidth of 100-Hz was moored on the west side of the deep basin transmitting a phase-modulated m-sequence signal every 15 min from February to October 2006. These periodic transmissions were recorded by a receiver moored approximately 150 km to the east of the source.

The receiver data was processed to yield the arrival structure and its temporal changes over the nine-month period (the summer segment is displayed in Figure 1). The observed temporal variability in the arrival structure and in the acoustic intensity was analyzed using time-series techniques with emphasis to elucidate the connection to the observed sound speed variability induced by the mesoscale ocean variability and the nonlinear transbasin internal tides and waves. From a pure observational perspective, key findings include:

1. The time-varying trend in the travel time variation tracks well with the “long mesoscale” ocean variability, and the intensity level exhibits biweekly and weekly fluctuations, manifestation of the “short mesoscale” ocean variability.
2. Travel time spectral peaks are aligned with each of the 6 internal, tidal constituents (right panel of Figure 2). However, intensity spectral peaks interestingly align only at the diurnal and semi-diurnal frequencies in the tidal band (left panel of Figure 2). Typical periods of the high-frequency nonlinear internal waves are captured as intensity spectral peaks in the supertidal band.
3. The variance in the travel time is dominated by the tidal-band fluctuations, with its temporal change exhibiting scalloping behavior with highs and lows aligning with periods of high and low internal tide/wave activities.
4. The variance in the intensity level is dominated by the supertidal-band fluctuations, with maximum/minimum variance periods appearing to coincide with the absence/presence of an early arrival.

In order to gain detailed understanding on the physics behind the empirical results, sound propagation modeling with input sound-speed fields constructed based on the concurrent oceanographic data, followed by model-data comparison analysis, is required. Such modeling analysis has already begun. Specifically, using the coupled-mode model of Chiu et al. (1996), the physics on the presence/absence of an earlier arrival or the splitting of the first arrival was explained (Chiu et al., 2008). Additionally, using a ray theory-based model (Chiu et al., 1994), the mean arrival structure consisting of a strong arrival followed by four weaker arrivals was successfully modeled (Figures 3 and 4). The next step is to model the variability.

IMPACT/APPLICATIONS

The oceanographic and acoustic data gathered in this field study should be valuable in helping to create models of shelfbreak regions suitable for assessing present and future Navy systems, acoustic as well as non-acoustic.

RELATED PROJECT

This fully integrated acoustics and oceanography experiment should extend the findings and data from SWARM, Shelfbreak PRIMER, ASIAEX and SW06, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

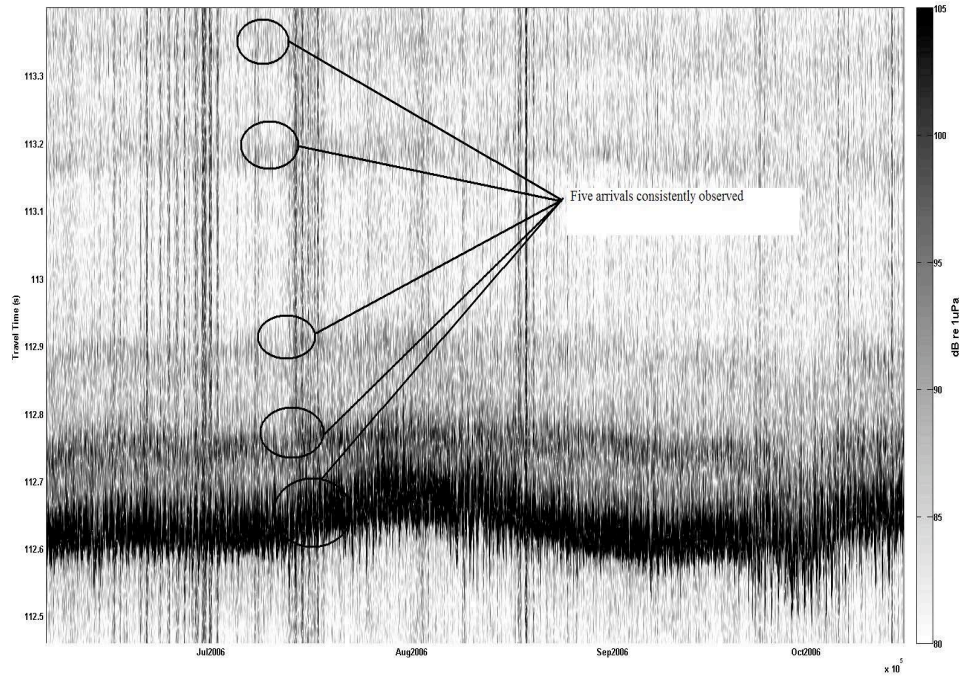


Figure 1. *The observed basin-transmission arrival structure as a function of transmission time.*

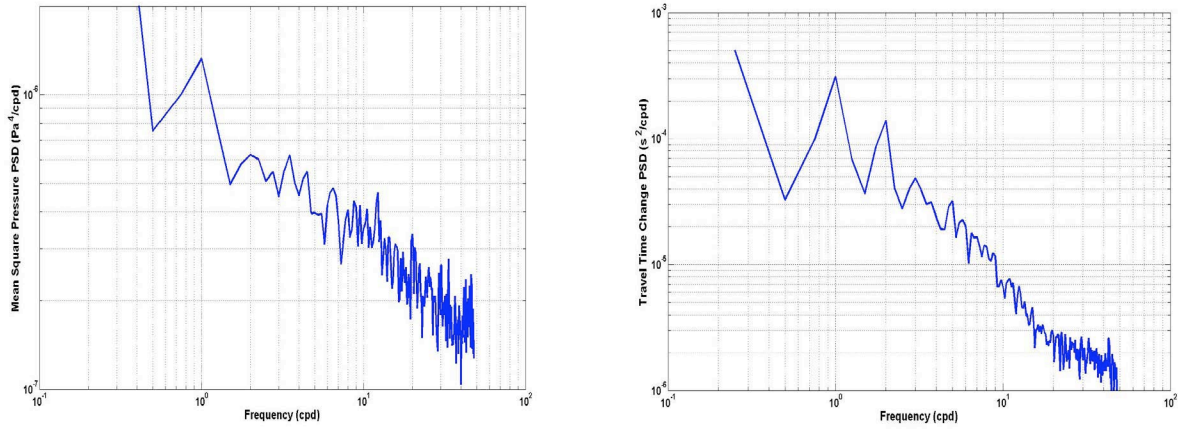


Figure 2. *Spectral densities of the observed mean square pressure (left) and arrival time (right).*

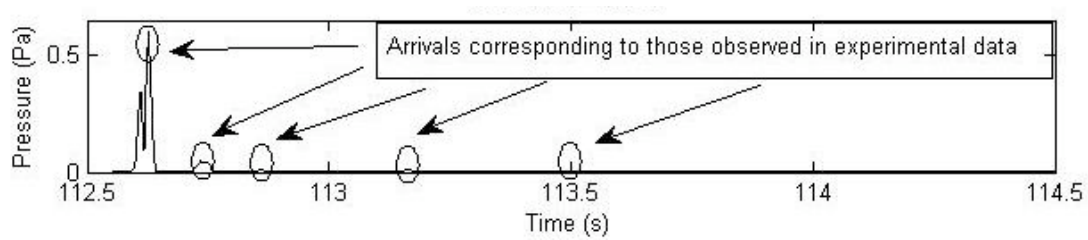


Figure 3. *Modeled mean arrival structure.*

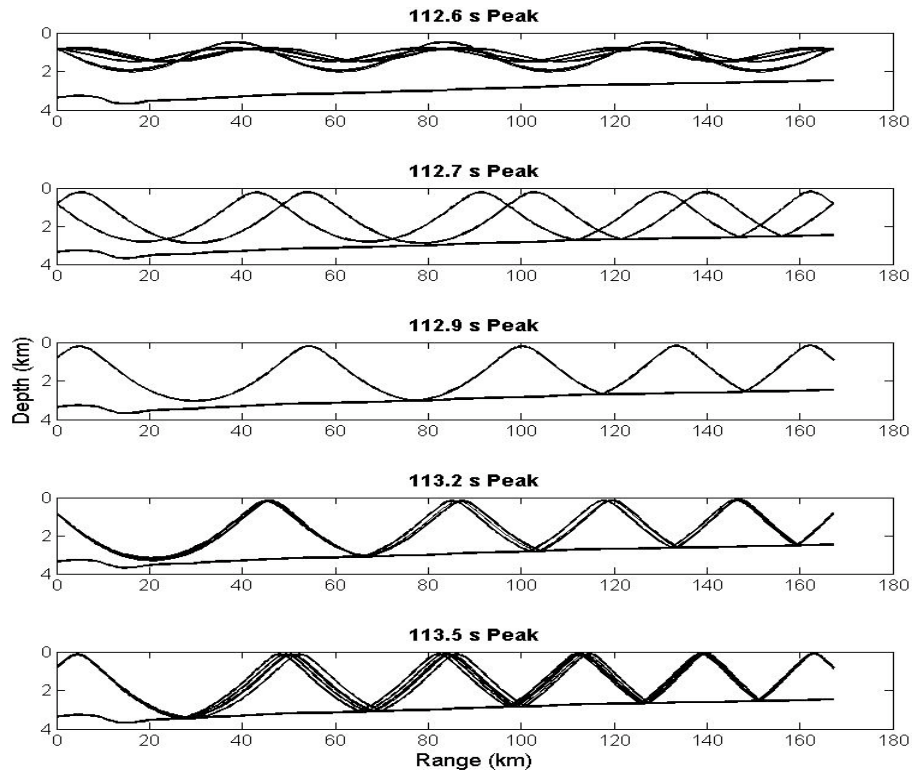


Figure 4. *The geometry and composition of the eigenray groups associated with each of the five observed arrivals.*

REFERENCES

- Chiu, C.-S., A.J. Semtner, J.H. Ort, and J. H. Miller, 1994: A ray variability analysis of sound transmission from Heard Island to California. *J. Acoust. Soc. Am.*, **96**(4) (1994) 2380-2388.
- Chiu, C. -S., J. H. Miller, and J. F. Lynch, 1996: Forward coupled-mode propagation modeling for coastal acoustic tomography. *J. Acoust. Soc. Amer.*, **99**, 793-802.
- Chiu, C.-S., D.B. Reeder, C.W. Miller, J.M. Reeves, S.R Ramp, Y.-J. Yang, R.-C. Wei, and C. Chen, 2008: Observed acoustic arrival structure and intensity variability induced by transbasin nonlinear internal waves in the South China Sea basin. *J. Acoust. Soc. Am.* **123**(5) (2008) 3588.
- Dyer, I., 1970: Statistics of sound propagation in the ocean. *J. Acoust. Soc. Amer.*, **48**, 337-345.
- Makris, N. C., 1996: The effect of saturated transmission scintillation on ocean acoustic intensity measurements. *J. Acoust. Soc. Amer.*, **100**, 769-783.

PUBLICATION

- Bernotavicius, C.S., Chiu, C.-S., Miller, C.W., Reeder, D.B., Wei, R.-C., Yang, Y.-J., L. Chiu, 2009: Modeling a 400-Hz signal transmission through the South China Sea Basin. *J. Comput. Acoust.* (submitted).